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Integrating LED Lighting Design Strategies with Side Daylighting Systems to Improve Interior Lighting Design of Office Buildings

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Abstract

A high contrast ratio between windows and surrounding walls may lead to office workers visual discomfort that could negatively affect their satisfaction and productivity. Consequently, occupants may try to adapt their working environment by closing blinds and/ or turning on the lights to enhance indoor visual comfort, which can reduce predicted energy savings. The hypothesis of this study is that reducing luminance contrast ratio on the window wall will improve window appearance which potentially will reduce visual discomfort and decrease workers interventions. Thus, this PhD research proposes a simple strategy to diminish the luminance contrast on the window wall by increasing the luminance of the areas surrounding the windows using supplementary light emitting diode (LED) systems. To test the hypothesis, this investigation will involve three experiments in different office layouts with various window types and orientations in Brisbane, Australia. It will assess user preferences for different luminance patterns in windowed offices featuring flexible, low-power LED lighting installations that allows multiple lighting design options on the window wall. Detailed luminance and illuminance measures will be used to match quantitative lighting design assessment to user preferences.

Windows; Visual comfort; Office room; Lighting energy consumption;
LED (light emitting diode); Daylighting systems

Good lighting design inside office buildings can provide the visual and psychological requirements of office workers (Bean, 2012). In addition, Dubois et al. (2011) holds the view that good lighting design can significantly diminish overall electric consumption of office buildings. Daylighting as part of lighting design strategies could be one of the most sustainable and effective systems for improving visual comfort (Hourani & Hammad, 2012), as well as reducing energy consumption for lighting (Gago, Muneer, Knez, & Köster, 2015). Office buildings commonly rely on side daylighting strategies through windows, in particular in high-rise buildings in modern cities for daylight harvesting (Huang, Niu, & Chung, 2014). It has also been reported that office workers generally prefer to have windows in their working environment that can provide both natural light and an outside view (Hirning, Isoardi, & Cowling, 2014). However, the issue with vertical windows is that even with a 100% glass area wall, light is unlikely to exceed 6m in distance from the window (Kevin Van Den & Meek, 2015). As a result there is a high contrast between the area next to the window, and deeper areas in the buildings (BSI, 2011); in addition, there is a high contrast ratio between the bright surface of the window and the surrounding surfaces (e.g. walls, ceiling) (Alrubaih et al., 2013). It is believed that the existence of high contrast of luminance in the field of view of occupants can lead to discomfort glare (Rodriquez & Pattini, 2014). Furthermore, Tashiro et al. (2015) hold the view that discomfort glare does not necessarily affect the work performance of individuals, but may cause certain physiological and psychological symptoms like headache or stress.

Literature review

According to Jakubiec and Reinhart (2012) discomfort glare is a neglected factor in the architecture design process due to lack of certainty about the meaning of present metrics, the advantages of such analyses and how they should be applied. For instance, a study in Brisbane found that roughly 56% of full-time employees, who work in buildings that are at least five star rated by the green building council of Australia (GBCA), experience discomfort glare from both daylight and electrical sources at their computer unit (Hirning et al., 2014). Feeling discomfort glare may lead to occupants intervention in lighting conditions through adapting their working environment by closing blinds and turning on the lights in order to improve indoor visual comfort (Aschehoug et al., 2000). As an example, a study among 123 buildings with installed photosensor-control systems illustrated that there is a comparatively constant relationship between the amount of illuminance from windows and turning on the lights by occupants, in particular when dimming control systems work perfectly (Heschong, Howlett, McHugh, & Pande, 2005). This study showed that as the window illuminance increases, the likelihood of turning on the lights will also increase to up to 60% to diminish luminance contrast between the window and surrounding areas. The impact of human intervention on lighting conditions can reduce energy savings; the largest field study on the effectiveness of side-lighting controls for daylighting showed that less than 25% of the predicted (modelled) energy savings arising from daylight harvesting systems were actually being realised in practice (Heschong et al., 2005).

Purpose and research question

The aim of this study is to improve user acceptance and visual comfort of day-lit offices at a low energy cost, and to reduce negative occupant interventions in these spaces. This study focuses on the window appearance when it is in the field of view of occupants. It is presumed that the window appearance can be improved through reducing the luminance contrast on the window wall by increasing the luminance of the areas surrounding the window using energy-efficient supplementary lighting, such as LEDs. Thus, bellow research question is proposed:

- Under what conditions, and how, can supplementary LED lighting systems be best integrated with windows in different office layouts and window types in Brisbane to enhance indoor visual comfort while reducing energy consumption of office buildings?

Research Method

This PhD research will involve three experiments in Brisbane, Australia. The first study will investigate the influence of the proposed LED system on the window appearance and perceived indoor visual quality. It will be based on subjective responses under sunny sky condition. Physical lighting measures will also be collected during each survey through using high dynamic range (HDR) imaging, luminance and illuminance meters. This experiment will be designed to learn about window appearance, and how occupants will respond to different luminance patterns brought about by changes to lighting design.

The second experiment will have somewhat similar approach to the first study. However, it will be conducted in an office with different window type and orientation. This experiment will be design to learn about users' preferences of the luminance ratio on the window wall. Thus, the subjects will be given the opportunity to set the luminance contrast on the window wall that they feel more comfortable with. In addition, this study will examine occupant responses when they expose to the average acceptable luminance ratio based on the results of the first experiment.

The third experiment will investigate the influence of proposed supplementary LED system on occupants' intention to intervene in lighting conditions through monitoring their behaviour before and after installing this system in their offices under different sky condition. In addition, this PhD research will test proposed design strategies using simulation tools like Diva-for-Rhino to appraise the solutions from both human factors (visual comfort) and energy efficiency perspectives. Diva-for-Rhino is an energy and daylighting modelling plug-in that can be used to appraise performance of buildings by obtaining photorealistic renderings, annual and individual time step glare measurement, radiation maps, climate based daylighting metrics, single thermal zone energy and load calculation, and LEED and CHPS daylighting compliance (Yun, Yoon, & Kim, 2014).

So far, the first study has been conducted in a typical office room facing south-west. 35 subjects participated in this experiment. The outcomes of this study suggest that a 27 W supplementary LED system can reduce the luminance contrast on the window wall by about 80%. In addition, the results report that this supplementary strategy could enhance the window appearance by approximately 21%, besides reducing the likelihood of users' intervention in lighting conditions by about 54%.

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PhD Student Biography

Mehdi

In 2014, Mehdi was admitted to a Doctor of Philosophy program at Queensland University of Technology (QUT). He was also awarded M. Arch in 2009 and B. Arch in 2006. A key area of his PhD research is improving lighting design in office buildings to enhance users' satisfaction, as well as reducing energy bills. The hypothesis of his study is that enhancing window appearance will reduce visual discomfort and decrease workers' interventions in lighting conditions. In addition, he is currently co-writing papers with his supervisors for disseminating his research at well-regarded conferences, which are ranked highly based on the Excellence in Research for Australia (ERA) ranking system, as well as planning to submit papers in Q1 journals based on the SCImago Journal and Country Ranking (SJR) system like the Building and Environment. His research interest areas fall into:

- Enhancing indoor lighting design of office buildings
- Reducing energy consumption of office buildings

Mehdi has also four years of teaching experience as a lecturer in Iran and supervised two undergraduate students during this period. Moreover, he has seven years of practice experience as a principal architect (designer and drafter) as well as a supervisor in different construction projects. During his professional experience Mehdi has been engaged in numerous successful residential, educational, commercial and landscape projects. Designing diverse building types, through concept and schematic design, in order to reach more developed and detailed stages, has been one of his duties in most of the projects with which he has been engaged. Developing and delivering progress reports, proposals, requirements, documentation and presentation lie amongst many other tasks he has completed in the role of a principal architect and/ or supervisor.